PROCEEDINGS

53. IWK

Internationales Wissenschaftliches Kolloquium
International Scientific Colloquium

Faculty of
Mechanical Engineering

PROSPECTS IN MECHANICAL ENGINEERING

8 - 12 September 2008

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Published by
Impressum

Publisher Herausgeber	Der Rektor der Technischen Universität Ilmenau Univ.-Prof. Dr. rer. nat. habil. Dr. h. c. Prof. h. c. Peter Scharff
Editor Redaktion	Referat Marketing und Studentische Angelegenheiten Andrea Schneider
	Fakultät für Maschinenbau Univ.-Prof. Dr.-Ing. habil. Peter Kurz, Univ.-Prof. Dr.-Ing. habil. Rainer Grünwald, Univ.-Prof. Dr.-Ing. habil. Prof. h. c. Dr. h. c. mult. Gerd Jäger, Dr.-Ing Beate Schlütter, Dipl.-Ing. Silke Stauche
Editorial Deadline Redaktionsschluss	17. August 2008
Publishing House Verlag	Verlag ISLE, Betriebsstätte des ISLE e.V. Werner-von-Siemens-Str. 16, 98693 Ilmenau

CD-ROM-Version:

Implementation Realisierung	Technische Universität Ilmenau Christian Weigel, Helge Drumm
Production Herstellung	CDA Datenträger Albrechts GmbH, 98529 Suhl/Albrechts

ISBN: 978-3-938843-40-6 (CD-ROM-Version)

Online-Version:

Implementation Realisierung	Universitätsbibliothek Ilmenau ilmedia Postfach 10 05 65 98684 Ilmenau

Home / Index:
http://www.db-thueringen.de/servlets/DocumentServlet?id=17534

53rd Internationales Wissenschaftliches Kolloquium
Technische Universität Ilmenau
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Gas-lubricated guidings – suitable for vacuum systems?

Introduction

The integration of gas-lubricated guidings into vacuum systems seems to be a paradox at first thought. Nevertheless, the research in this field has been intensified in recent years. More and more future measurement and semiconductor processes have to be carried out under vacuum conditions to obtain a higher accuracy or to produce smaller structures. Positioning systems with nanometer-scale motion accuracy are mandatory for many of these processes. Due to the minimal friction and a stick-slip-free motion, gas-lubricated guidings are predestined for such applications. In the present work, various integration concepts and the dimensioning of the required seal system are discussed.

Integration concepts

For the integration of gas-lubricated guidings into vacuum systems, two different concepts have been established. Both concepts have in common that the guiding has to be equipped with an efficient seal system. The pressure is gradually decreased by multiple seal stages typically consisting of an evacuable exhaust groove and a seal gap (Fig. 1). Thus, the gas leakage flow into the vacuum environment can be controlled.

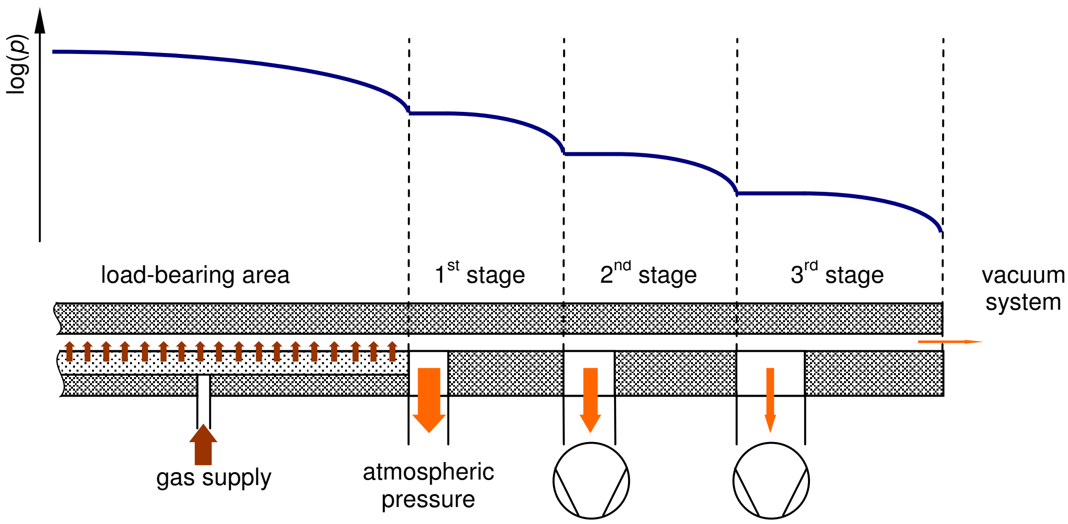
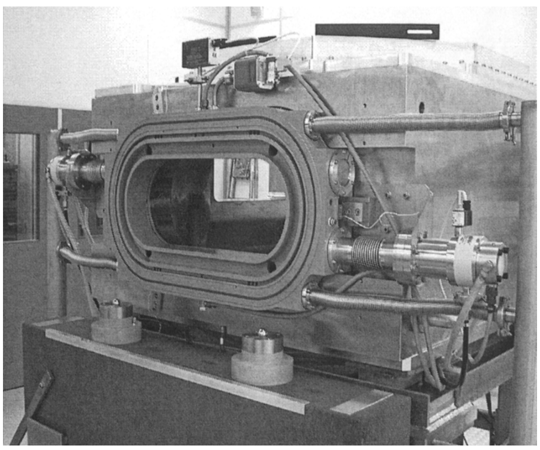


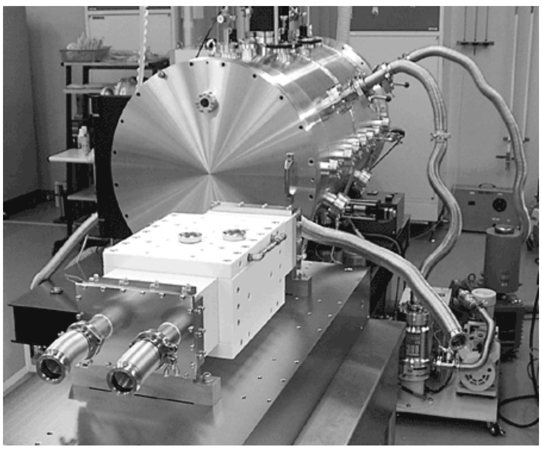
Fig.1 Schematic of a typical three-stage seal system and pressure distribution

The first concept is the integration of the guiding into a wall of the vacuum chamber [1-3]. A guiding plate is movably arranged above a window in the chamber wall that is enclosed by the seal system (Fig. 2a). The stationary seal allows to exhaust the gas with a high effective pumping speed (very short exhaust tubes with large cross- sectional area). The bearing pads are fixed to the wall and operate outside the vacuum chamber at ambient pressure. Due to the impact of the atmospheric pressure on the guiding plate, the bearing pads are heavily preloaded. Therefore, the guidings can achieve a high static stiffness. On the other hand, the guiding plate has to be designed very bend-proof. Note, that the motion of the guiding plate causes an alternating load especially at large motion ranges. On the surface of the guiding plate exposed to the atmosphere, water molecules adhere. The molecules can desorb during the movement once the surface is under vacuum conditions and then derogate the quality of the vacuum.

The second concept comprises guidings directly operating inside the vacuum chamber (Fig. 2b) [4-7]. The bearing pads enclosed by the seal system are usually integrated in the movable part of the guiding. Hence, the exhaust of the gas is problematic. To avoid or minimise reactive forces, high-flexible synthetic exhaust tubes are used or the tubes are integrated into the guiding components and connected by separately sealed contact-free ports. However, the effective pumping speed of the exhaust stages is comparatively low. In general, the first exhaust stage is an atmospheric stage with a non-evacuated exhaust groove. The atmospheric pressure within the first stage increases the bearing force but decreases the static stiffness of the bearing pads. Furthermore, water can intrude through the exhaust tubes of this stage into the vacuum system. Bearing pads with an evacuated first exhaust stage achieve a higher static stiffness but a lower dynamic stiffness.



a) Guiding integrated into the wall of the vacuum chamber [3]

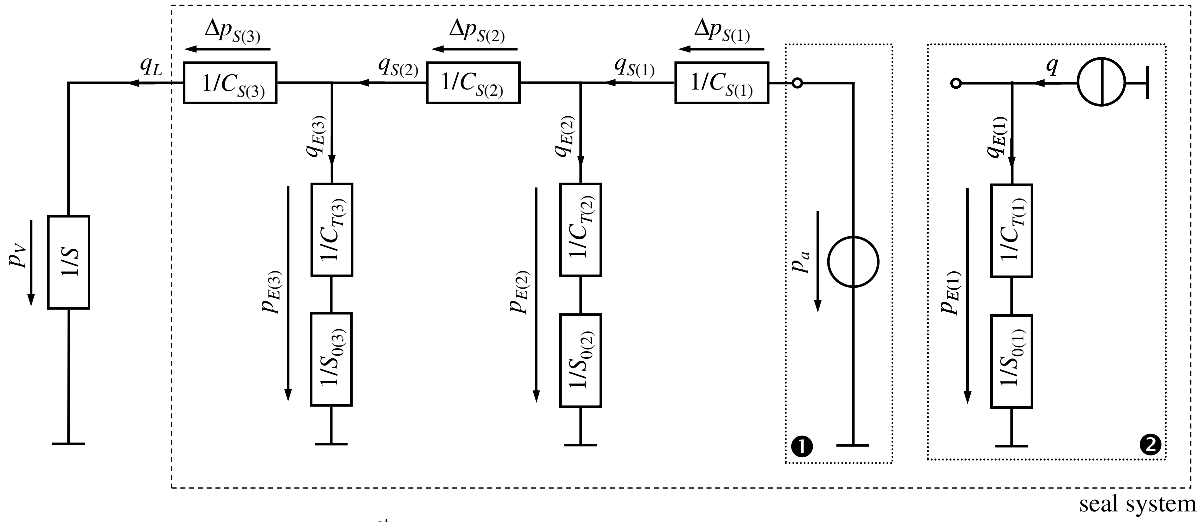


b) Guiding directly operating inside the vacuum chamber [4]

Fig.2 Vacuum compatible gas-lubricated guidings

Design of the seal system

The design of the complete seal system is very complex because different flow regimes from continuums flow to molecular flow have to be handled. The influence of a single design-parameter on the leakage flow is not obvious at once. To understand the interaction of all parameters, the analogy between the fluidic system and an electric network (Fig.3) can be utilised. In Fig. 3, S is the pumping speed of the vacuum pumps, C_S and C_T the conductances of the seal gaps and exhaust tubes, p_E the pressure of the exhaust grooves, p_a the atmospheric pressure, q the gas load of the bearing pads and q_L the gas leakage flow.



❶ atmospheric 1st exhaust stage with a non-evacuated exhaust groove

❷ evacuated 1st exhaust stage

Fig.3 Electric network in analogy to a fluidic three-stage seal system

As a result, the leakage flow depends on the product of the ratios of the conductance of the seal gap and the effective pumping speed of each exhaust stage. The number of exhaust stages has the major impact on the leakage rate. It approximately declines with the gap height to the power of two times the number of exhaust stages. A large length of the seal gaps does not significantly reduce the leakage rate. An additional exhaust stage within the same overall seal system size is more efficient. The length of the exhaust tubes is to be minimised and the cross-sectional area is to be maximised to achieve high effective pumping speeds. The cross-sectional area of exhaust tubes with a molecular flow regime has to be larger than that of tubes with a continuums flow regime. Considering these design rules, a vacuum level in the order of 10^{-4} Pa can be achieved within the vacuum chamber with a two-stage seal system.

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